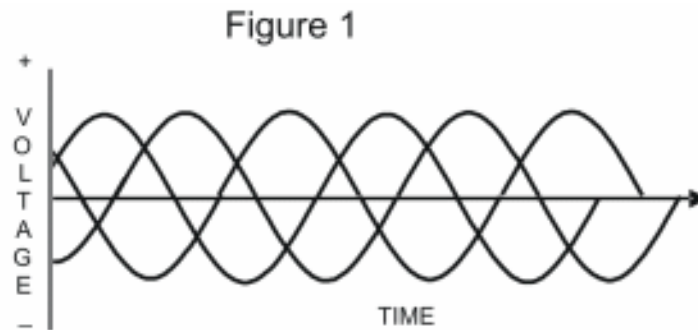## Three Phase Electricity Supplies and Systems

The generation and supply of electricity within the U.K is achieved through the use of a 3-phase system.
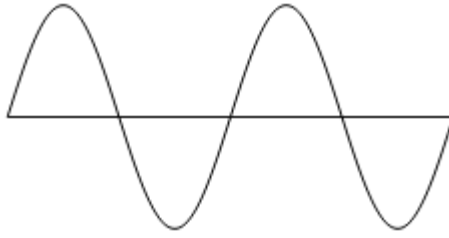

Figure 1

This consists of 3 separate phase conductors along with a neutral conductor transmitting supplies to a given destination.

Simple three phase transmission

Consider a single phase generator to generate a single phase electricity supply. It would consist of a coil of wire which is rotated within a magnetic field.
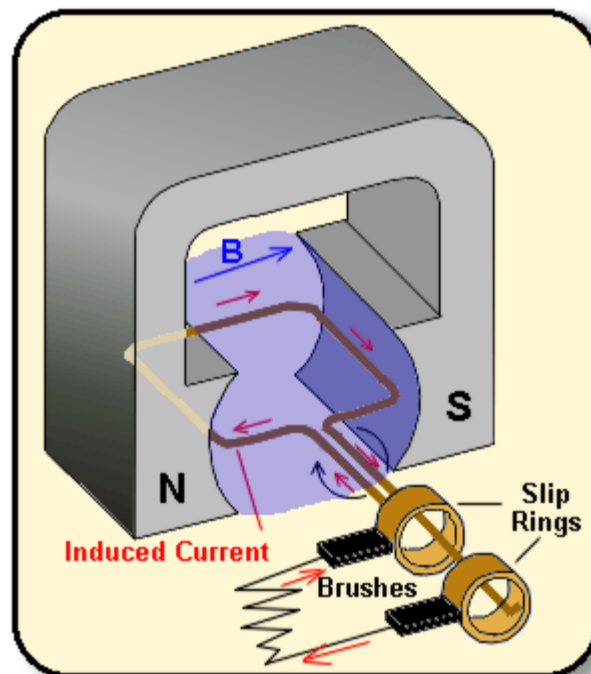
It's output would be as shown below.

If we took three of these generators (A,B & C) and positioned them equidistantly (120°
apart) around a rotating magnet we would generate three separate a.c. waveforms
each with a phase displacement of 120° from each other.


Waveform of a
3-phase system.
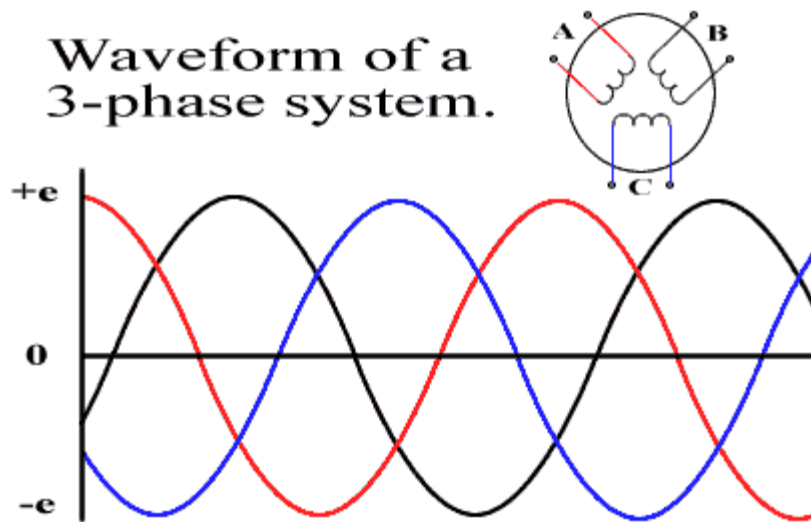
Such an arrangement would provide us with a 3 phase supply but we would need 6
conductors in order for it to function. However if we take each coil and interconnect it
with the other coils in particular ways we can achieve a three phase supply in either a 3
wire (Delta) system, or a 4 wire (Star) system.

Delta Connection (3-phase, 3 wire system)

Using this method of connection each of the three coil windings are wound in such a
way so they each have a start and a finish to their winding.

Then the finish of winding 1 is connected to the start of winding 2. The finish of winding
2 is connected to the start of winding 3. The start of winding 3 is connected to the start
of winding 1.
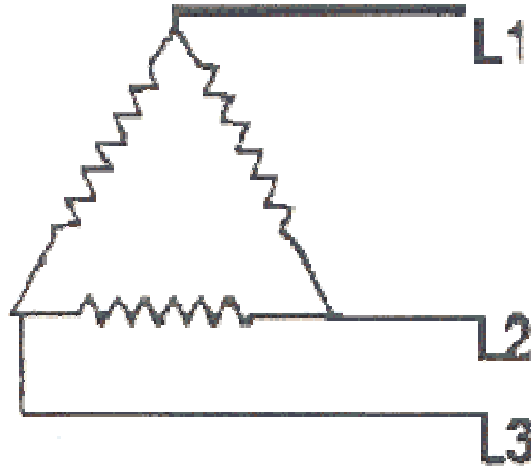
On the diagram above mark each winding, A,B or C, then mark their starts and finishes.

The supply is then taken from the interconnection of each winding combination as shown above. This means we can achieve a 3-phase system using only 3 wires.

There is an alternative connection that may be made for the provision of a three phase supply which is known as 'Star' connection.

Star Connection (3-phase, 4 wire system)

The three coils are also wound so that each has a definite start and finish to their winding.

However to provide a star connection the starts of each winding are connected together at a common point known as the star point. The phase supplies are then taken from the finish of each winding to the point of utilisation. The star point may also have a fourth wire connected to it (known as the neutral conductor) which is then fed along with the three phase conductors to the point of utilisation.
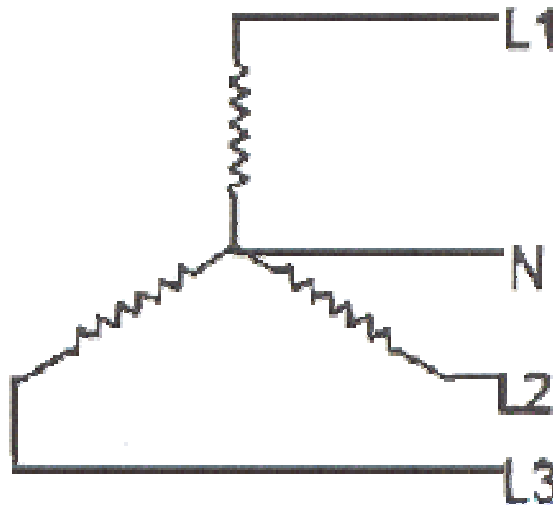
Remember!

Delta = 3 phase, 3 wire system

Star = 3 phase, 4 wire system (3 phase + Neutral)

Maths of star and delta systems

The voltages and currents that exist within a three phase system have particular relationships.

Voltages measured across any phase winding are known as 'Phase Voltages' and are symbolised V_P.
Voltages measured between any pair of lines are known as 'Line voltages' and are symbolised V_L.

Currents measured through any phase winding are known as 'Phase Currents' and are symbolised I_P.
Currents flowing along any line are known as 'Line currents' and are symbolised I_L.

Indicate all line and phase voltages and all line and phase currents in the diagrams below.
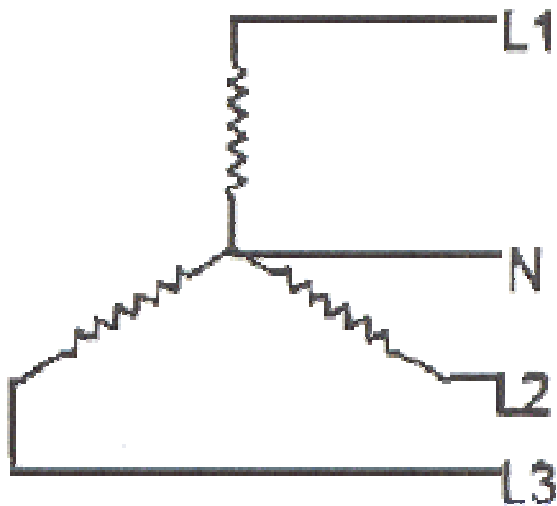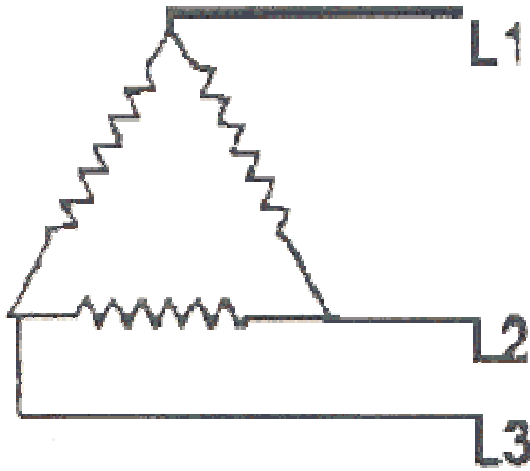
Delta systems

Voltage Relationships

VL =VP   Therefore   VP = VL

Current Relationships

IL = 1.732 x IP   &   IP = $\dfrac{IL}{1.732}$

Star Systems

Voltage Relationships

VL = 1.732 x VP   &   VP = $\dfrac{VL}{1.732}$

Current Relationships

IL = IP Therefore   IP = IL

You must remember these relationships by committing them to memory.

Note! Rather than use 1.732 many texts will use the square root of 3 which equates to 1.732.

$$\sqrt{3}$$

Progress

A star connected system has phase voltages of 300v and phase currents of 12A. Calculate line voltages and currents.

If the system above was a delta connected system, calculate the line voltages and currents.

Balanced and unbalanced systems

Star and delta systems can also be connected as loads. Many three phase motors will be connected in delta since only three wires are required to make the connection.

Star connections are often used as a means of connecting single phase loads to a 3 phase supply, such as in the case of a street of domestic dwellings.

A **delta connected load** will have **identical phase impedances**. The impedance of each phase will therefore be identical both in terms of it's **magnitude AND phase angle**. When this is the case the current that flows in each phase will be identical and the sum of the currents will be zero. **The system is said to be balanced** and there is no need for a 4th wire (neutral conductor).

It is also possible to have a **star connected load** where the **impedance of each phase is identical** in terms of it's **magnitude and phase angle**. As with the delta system this will lead to identical phase currents and no excess current to flow back to neutral. Again, **the system is said to be balanced** and there is no need for a 4th wire (neutral conductor).

It is more usual however, to connect dissimilar loads to each phase of a star system. This will result in differences in phase currents which in turn will create some 'leftover' current which will flow back along the 4th wire (neutral) to the star point of the supply origin. Such a system is known as an **unbalanced system** and usually arises as a result of connecting separate single phase loads to each phase of a three phase star connection.

Progress

What is meant by a 3 phase balanced system?

Is there any need for a 4th wire (neutral) in such a system?

How does an unbalanced system differ?

What function does the 4th wire serve in an unbalanced system.

Which type of 3 phase system is more likely to be found with an unbalanced load?

For Level 3 students a powerpoint presentation exists to explain the calculation of neutral current in a 3 phase balanced and unbalanced system.

Power in three phase sytems.

Each phase of a 3 phase system will result in some power consumption.

If the system you are dealing with is balanced there will be an equal power dissipation per phase and therefore it is necessary only to calculate the power dissipated in one phase and multiply the result by 3 (for the 3 phases).

When doing this however you must remember that each phase is an a.c system and as such the power factor is required in addition to phase voltage and current.

$$\text{Power/phase} = V_p I_p \cos\theta$$

If the system is balanced:
$$\text{Total Power} = 3 V_p I_p \cos\theta$$

For an unbalanced system it is necessary to calculate each phase power in turn and add them in order to find total power.

An alternative power formula exists which utilises the line voltages and currents:

$$\text{Total Power} = 1.732 \times V_L I_L \cos\theta$$

These formula apply to both Star and Delta connected systems equally.

Progress

A star connected balanced load has a phase voltage of 230v and line current of 9A. The system power factor is 0.65.

Calculate the total power for the system using both total power formulae.

Once you have calculated total power calculate the power per phase.

A delta connected load has a phase voltage of 180v, a phase current of 22A and a phase angle per phase of 25°. Calculate the total power dissipated in the load.

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